International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249–6890; ISSN (E): 2249–8001
Vol. 9, Issue 5, Oct 2019, 147–156

ENERGY POTENTIAL OF SUGAR-MILL BY PRODUCT PRESS-MUD THROUGH PYROLYSIS PROCESS

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ABSTRACT

Press-mud is the sugar industry left-over produced from the filtration of the sugar cane juice during the production of sugar. At present, it is a good source of fertilizer and utilized in soil quality enhancement in India. Press-mud as per composition contains higher percentage of combustibles that can be the good source of renewable energy and viable for economic growth of the sugar plant. A detailed study has been carried out to pyrolyze the Press-mud to acquire the fuel gases potential for energy generation. This study is focused on the modelling, simulation and performance analysis of Press-mud pyrolysis process using Aspen Plus Simulation software. The proximate and ultimate analysis has been carried out followed by simulation of pyrolysis process. The various parameters i.e. pyrolysis temperature, heating rate etc. have been discussed for Press-mud as a feedstock

KEYORDS: Sugar Cane, Press-Mud, Pyrolysis Temperature & Renewable Energy

Received: Apr 13, 2019; **Accepted:** May 03, 2019; **Published:** Sep 04, 2019; **Paper Id.:** IJMPERDOCT201914

Original Article

INTRODUCTION

To achieve the renewable energy, targeting an efficient disposition of the current bioenergy potential is essential.

In the sugar mill, sugarcane juice is obtained by crushing the sugarcane in crushers. Sugarcane juice comprises a huge amount of liquefied and suspended solid elements. These solid particles are parted by applying the filtration or clarification procedure. The precipitation of solid particles takes place during the clarification process and these solid particles settle down at the bottom of the tank, and only liquid as a juice left. The precipitated solid particles are called press mud (PM) [Kranti Kuruti et al; 2015]

Press mud is sugar industry waste, obtainable from the sugar production process in sugar mills. Most of the Indian sugar mills adopted double sulphitation process for clarification, produce a lot of press mud (filter cake) as a by-product or waste, need to be utilized [P. B. Gangavati et al; 2005]. Pressmud is a mushy, squashy, shapeless and shady brown solid comprising sugar, fiber and syrupy colloids with cane wax, albuminoids, mineral salts, dirt elements and inorganic essentials in different quantities (Yadav 1992; Joshi and Sharma 2010). Pressmud has different qualities as it saves soil attrition, crusting and cracking when mixing with it also regulates soil pH value, recovers drainage and endorses usual bacterial and microbial development in the earth. [Tandon etal; 1995]

Along with the above uses, the press mud is also a source of energy in the form of biogas with 5–15% of sugar particles. Press mud is either used for soil enhancement in open fields or traded as undeveloped compost to agriculturalists. At present, press mud is utilizing in big amount in bio-composting, where it is preserved with the

spent wash from the distillery (Padmanabhan et al. 1993). The dehydrated press mud can be utilized for energy production by direct combustion with higher flammable particles (Gupta et al. 2011). Pressmud wax is a possible alternative option for high prized carnauba wax extensively used in beauty products, nutrition and medicines production [Taylor 2000].

Pressmud has about 68–70% of moisture, 24–28% of combustibles and 6–8% of ash. It is very rich in micronutrients for agricultural crops and horticulture: nitrogen 1.9%, phosphorous 1.8%, potassium 0.9%, calcium 4.3%, magnesium 0.7%, sulfur 3.2%, sodium 0.1%, manganese 0.034%, zinc 0.008% and copper 0.053%. It is estimated that crushing of 100 kg of sugarcane produce 3 kg of Pressmud cake as by-product. [Neha Gupta et al; 2011]. Pressmud, can be the source of energy through pyrolysis and gasification process. Press mud dehydrated and densified first, and after pyrolysis and gasification, it produces solid charcoal, liquid and gaseous products. [M. L. Dotaniya; 2017]

Press mud comprises a satisfactory quantity of cellulose (22.3%) and hemicellulose (21.67%) calculated on the dry basis, hence, it can also be applied for additional acetone-butanol-ethanol (ABE) production, [Pranhita R. Nimbalkar et al; 2010] Researchers also done investigations with respect to fermentation of Pressmud. [Kranti Kuruti et al; 2015]

Such a further applicability of press mud, very few investigators has done investigation to recognize the thermal degradation phenomenon of Pressmud, (pyrolysis and gasification) and its kinetics. Though, it seems the need of more study on press mud, an important agro-industrial waste, which is accessible in abundantly in sugar mills and can improve the energy and economic viability of the plant.

BIOMASS PYROLYSIS

Pyrolysis is a thermochemical decomposition of biomass into a range of useful products, either in the total absence of oxidizing agents or with a limited supply that does not permit gasification to an appreciable extent. Pyrolysis involves heating biomass or other feed in the absence of air or oxygen at a specified rate to a maximum temperature, known as the pyrolysis temperature and holding it there for a specified time. The nature of its product depends on several factors, including pyrolysis temperature and heating rate. During pyrolysis, large complex hydrocarbon molecules of biomass break down into relatively smaller and simpler molecules of gas, liquid, and char.

The normal temperature range during the pyrolysis process is around 500°C. With lingo cellulosic biomass as raw material, the preliminary product of pyrolysis consist condensable gases, which further disrupted into non-condensable gases (CO, CO_2, H_2, and CH_4), liquid (bio oil) and solid char.

The pyrolysis process may be characterized by a general reaction given by

$$C_nH_mO_p \rightarrow \sum_{liquid} C_xH_yO_z + \sum_{gas} C_aH_bO_c + H_2O + C(char) \quad (1)$$

The chemical conversion of Biomass using pyrolysis process is primarily in the investigation stage, and almost no profitable pyrolysis setup occurs till date [Bridgwater AV et al; 2012, Meier D et al; 2013, J. F. Peters et al; 2017]. There is shortage of authentic plant working data; the system analysis with the help of simulation software has been carried out to assess the amount of biofuel that can be generated after pyrolysis of press mud generated after crushing of sugarcane in a local sugar mill.

MATERIALS AND METHODS

Sample Collection and Preparation

Table 1: Value Obtained for Ultimate and Proximate Analysis

Characteristics	Value % [N. Gupta et al]	Value % [Khursheed B. Ansari and Vilas G. Gaikar]	Present Value %
Moisture	3.52	4.9	4.1
Ash	25.9	9.3	23.8
Volatile Matter	61.2	66.81	62
C	33.73	49.2	41.4
H	3.92	7.5	4.2
N	2.36	4.4	2.6
S	0	Not Detected	0
Calorific Value	16960.97Joules/gm	Not calculated	17032 Joules/gm

The quality of sugarcane varies from place to place, thus characteristics of press mud also varies. Press mud sample for the study was obtained from a local Sugar Mill, Kareli, and M P India. As the sample having excess amount of moisture, it first dehumidified using sun dried method, and converted into powder form for further analysis. The powdery press mud was stored in airtight container. The ultimate and proximate analysis of these press mud sample was carried out as per ASTM standard method. The ultimate analysis of the sample was determined by using Perkin Elmer Analyzer at Nano-materials Characterization Laboratory, Mody University, Lakshamangarh, India and for finding out the HHV, a bomb calorimeter is utilized. The value obtained for ultimate, proximate and HHV is depicted in table 1.

Simulation

In general, a chemical process consists of chemical components, or different species, that are subject to physical or chemical treatment, or both. The goal of applying such treatment steps is basically to add a value or convert the raw, cheap material(s) into valuable, final finished products (gold). The physical treatment steps may include mixing, separation (de-mixing), such as absorption, distillation, and extraction, and heating/cooling with or without a phase change. On the other hand, the chemical treatment step involves a single or set of parallel, series, or mixed reactions, which results in a change of chemical identity of each of reacting species. In Aspen Plus simulation tool, the treatment steps are visualized in the flow sheet simulator as components being transported from a unit (or block) to another through process streams.

To carry out the continuous, steady state pyrolysis of Press mud, the Aspen Plus software is considered. Since pyrolysis process consists hundreds of individual compounds, its modelling in process simulations is a complicated assignment and needs foremost simplifications. To carry out the pyrolysis process, the following assumptions have been made:

- The energy loss during the process is neglected.
- The proper mixing of feedstock is considered
- The thermal equilibrium is considered for reactions.

The pyrolysis model considered for the study is shown in figure 1.

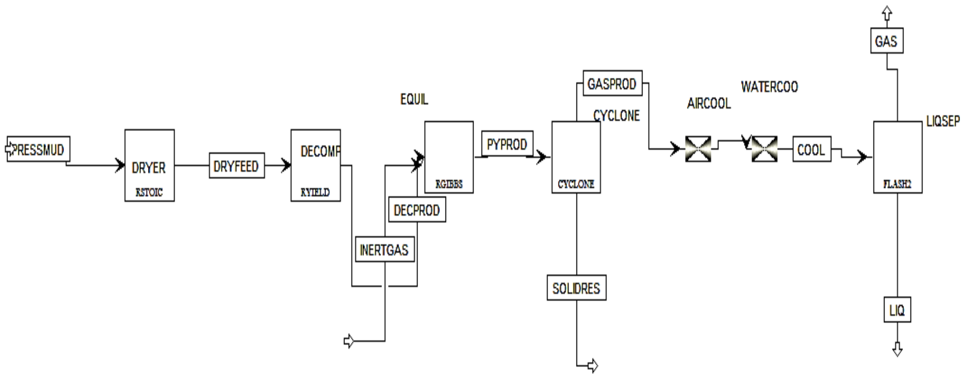

Figure 1: Process Flow Diagram for Pyrolysis Process [A. Visconti Et Al; 2015].

Table 2: Description of the Unit Operations of the Aspen Blocks

Aspen Plus Name	Block Name	Function
RYield	DECOMP	Decomposition of Pressmud at fixed temperature and pressure
Seperator	LIQSEP	Seperation of Liquid and Gas
RStoic	DRYER	Heat up the Pressmud Feed
RGibbs	EQUIL	Pyrolysis of Feed
Cyclone	CYCLONE	The unreacted solid and gas product is separated in a cyclone.

Figure 1 shows the flow chart of Press mud Pyrolysis simulation using Aspen Plus, and table 2 provides the brief explanations of the unit processes of the blocks. The stream Press mud was identified as a nonconventional stream, and it was characterized with the help of proximate and elemental analyses. The pressure and temperature of the feed is considered as 1 bar and 25°C, respectively. When Press mud was fed into the process, the initial stage was the drying stage and carry out in the block R Stoic block named DRYER. In DRYER, the press mud as wet feedstock was heated for removal of water content.

The decomposition of biomass (press mud) were simulated by an R-Yield block called DECOMP and pyrolysis process has been performed in RGibbs block named EQUIL, in which the chemical equilibrium was determined by minimizing the Gibbs free energy, and it does not require reaction stoichiometry. The decomposed press mud at output condition and the inert gas stream at 25°C temperature and atmospheric pressure insert the EQUIL block. For cooling the gas product, the air and water coolers are applied, which brings the temperature up to 40°C after pyrolysis. The Separator block named LIQSEP is applied at last to separate out the Liquid and gas product.

Table 3: Operating Condition and Gasification Parameters

Items	Parameters	Description
Stream Class	MIXCINC	Both conventional and nonconventional solids are present, but there is no particle size distribution
Property method	PK-BM	Peng Robinson cubic equation of state with the Boston-Mathias alpha function
Non-Conventional Properties	Enthalpy-HCOALGEN Density-DCOALIGHT	Different empirical correlations for heat of combustion, heat of formation and heat capacity are included in the HCOALGEN model.

Table 3: Contd.,		
Feed	Press mud (Sugar industry waste)	Specified as it's ultimate, proximate analysis at 25˚C temperature and 1 atm pressure calculated in laboratory.
	Inert Gas	1% O_2, 99% N_2 at atmospheric temperature and pressure condition.
Pyrolysis Condition		400˚C temperature and 1 atm pressure condition.

SIMULATION RESULTS

The pyrolysis gas consists mainly of such combustible components as hydrogen, carbon monoxide, and methane. The yields of resulting products from the pyrolysis of press mud were investigated under the variables i.e. pyrolysis temperature, heating rate and Lower heating value of gas product

The effect of pyrolysis temperature and heating rate on the pyrolysis product produces; simulation was carried out at particle size up to 2 mm.

It is found out that the char yield had a variation, as the pyrolysis heating rate increased from 100 to 500° C/unit time in simulation, with constant pyrolysis temperature 500°C (figure 2). The char yield decreases, but the Bio oil increases as the pyrolysis temperature increased from 400 to 800 °C. (figure 3).

Hydrogen, Carbon mono oxide, Carbon dioxide and Methane are the four main components that are produced in the gaseous form, resulting from the simulated pyrolysis at high temperature. The component quantity varying along with the pyrolysis temperature is shown in figure 4. It can be observed that Hydrogen and Carbon monoxide quantity increases while the other two carbon dioxide and methane decreases with the increment in pyrolysis temperature up to 550°C. The chemical changes occurs during the pyrolysis is of Endothermic nature, which is then supported by high temperature, as the pyrolysis temperature increases and yield higher value of Hydrogen and Carbon monoxide by consuming methane and carbon dioxide. The Heating Value also decreases as the pyrolysis temperature increases due to the fact that at high temperature, the endothermic reactions convert methane into hydrogen and carbon mono oxide (figure 5). This condition adverse after the temperature 550°C, the increment in of Hydrogen and CO values results in increment of heating value, and it reaches the value of 15.75 MJ/kg of Pressmud pyrolysis at temperature upto 800°C

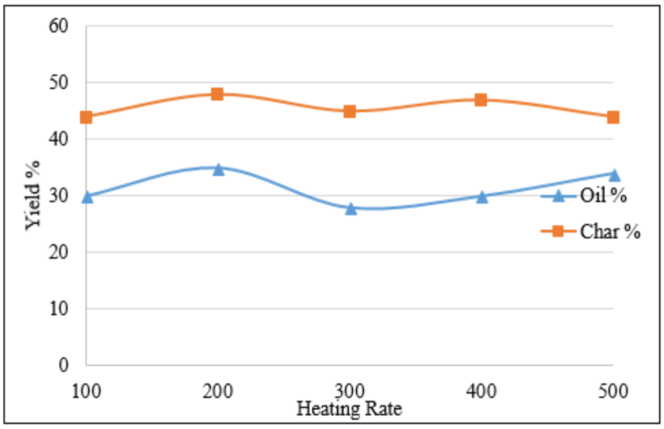

Figure 2: Char and Bio-Oil Yields Dependency on Heating Rate.

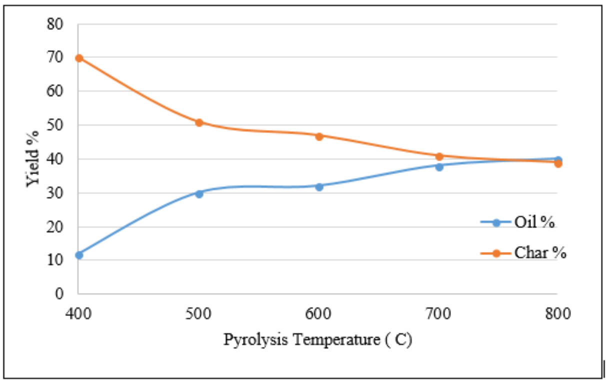

Figure 3: Char and Bio-Oil Yields Dependency on Pyrolysis Temperature (°C).

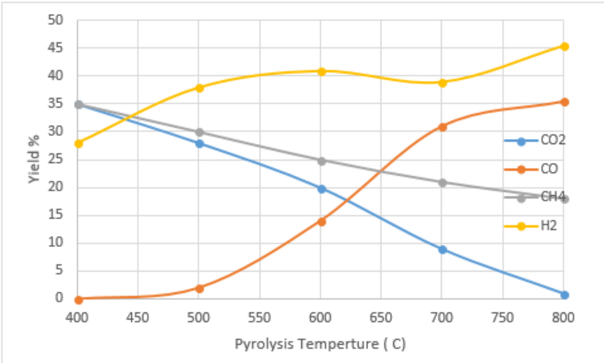

Figure 4: Effect of Pyrolysis Temperature on Gas Product Yields.

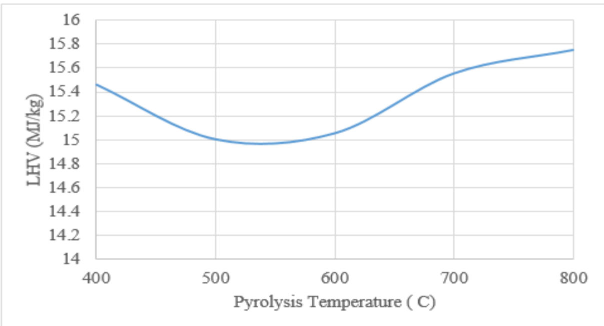

Figure 5: Effect of Pyrolysis Temperature on Gas Product Heating Value in MJ/Kg.

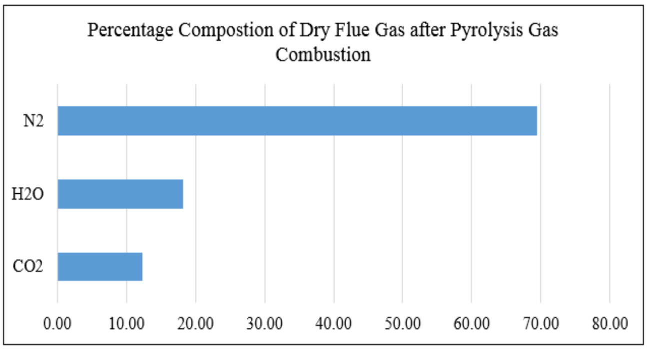

Figure 6: Percentage Composition of Dry Flue Gas After Pyrolysis Gas Combustion.

Table 4: The Percentage Composition of Product of Pyrolysis Gas Combustion

Reactants	Mols per mol of fuel	O_2 required	Products	
			CO_2	H_2O
CO	0.355	0.1775	0.355	
H_2	0.455	0.2275		0.455
CH_4	0.17	0.34	0.17	0.34
CO_2	0.01		0.01	
N_2	0.01			
	1	0.745	0.535	0.795

Table 5: The Percentage Composition of Dry Flue Gas After Pyrolysis Gas Combustion

Products	Mols per mo. Fuel	% Volume	Molecular Mass (M) kg per mol. Fuel	Kg per mol. Fuel	% by mass
CO_2	0.535	12.28	44	23.54	19.20
H_2O	0.795	18.24	18	14.31	11.67
N_2	3.028	69.48	28	84.78	69.14
	4.358	100.00		122.634	100

With the two variables, the thermal environment and the pyrolysis temperature, the feedstock yield primarily biochar at low temperatures, less than 400°C, with less heating rate, and mainly gases at high temperatures, near about 800°C, with high heating rates.

Table 4 and 5 show the scheming to find out the percentage configuration of after burn gas, produced after combustion of Pyro Gas produced after pyrolysis of pressmud. The after-burn gas constitutions are N2, H2O and CO2. About 19.2 % (by volume) CO2 is produced which affect the environment

The analysis of product by mass and by volume is given in Table 5.

DISCUSSIONS

Press mud has energy content more than half of the energy content of the average coal found in India. It has high ash content, comparable to coal and high volatile matter and fixed carbon as compared to average coal. [P. B. Gangavati et al]. With press mud as feedstock, it yields gases, a carbonaceous residue (char) and a liquid fraction (bio-oil). At different pyrolysis temperature and heating rate yields of oil and gaseous products varies, and it is user dependent and can be vary as per the requirement. By changing the reaction environments, the yield can be controlled.

It has been observed while pyrolysis of Pressmud that the fast pyrolysis exploits the oil yield at advanced temperatures, though slow pyrolysis reaches maximum char yields at somewhat inferior temperatures. Pyrolysis liquid from Pressmud is also can be the one alternative to substitute fossil fuels and feed stocks. This liquid is also a possible source of incomes for sugar mills that have Pressmud for disposal. Bio-oil would also be a stimulating fuel for minor scale

heat or power production in a plant. However, bio oil is new for market, which is relatively different from conventional liquid fuels, and numerous trial left overs to be overwhelmed. Thus for the study, the gaseous products have been considered as the prime source of energy.

The above analysis indicates that the press mud has the sufficient suitability as a fuel through the pyrolysis process, and can improve the income of sugar plant. About 15 to 15.5 MJ of energy can be generated by per kg of pressmud. Generally, one ton of raw sugar-cane produces around 100 kg of sugar, 270 kg of dry bagasse and 35 kg of molasses and 30 kg of press mud (Garcı`a-Pèrez et al., 2002a). If complete one-year plant production is considered, the total of 4500 MT of sugarcane crushing capacity with 3.27 Lakh MT sugar cane crushed annually, the total amount of Pressmud production is approximately 3000000 kg. The potential of heat/power production is about 45000000–46500000 MJ. The sludge comes from the digester is also a good fertilizer, which in turn utilize for soil up gradation.

CONCLUSIONS

The results depict that the press mud could be a very significant source of green energy. This work presents a study regarding the modeling and simulation of pressmud pyrolysis processes. A Simulation is carried out for pressmud pyrolysis, in direction to study the outcome of primary parameters on the production of gaseous products that can be further utilized as fuel. It can be concluded that the pressmud can be the source of renewable energy by various decomposition processes, and alternatively improve the sugar mill economics in India.

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